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Studies of Frenching of Tobacco

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Frenching of tobacco is described in a number of publications, some of which report work on its cause and control (2, 5, 6, 11, 13, 14 and others). Previous studies at this Experiment Station led to the belief that it is a nitrogen deficiency disease (13). These were mainly with Turkish tobacco in the greenhouse, using a woodland soil from the Experiment Station farm. River sand to which pulverized limestone was added was used in one experiment. Frenching usually developt at about the same time that symptoms of nitrogen deficiency appeared in the lower leaves. When sufficient nitrogen was added frenching did not develop, and such additions to frenched plants brought about recovery. It was stated, however, that frenching in the field was not observed to be associated with symptoms of nitrogen deficiency. It was also stated that much frenching was observed at the Campbellsville soil experiment field in 1927 on limed plots but none on unlimed plots, and an instance was reported where frenching apparently was induced by limestome dust blown or washed from a macadam road on to a field of White Burley tobacco.

The studies were continued, mainly, to obtain more information on the effect of soil reaction or liming on frenching. The rapid increase in use of lime materials in the State, and consequent more frequent growing of tobacco on limed land, gave this an added importance. Early in these later studies, frenching was found to develop in plants in a number of limed soils

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when much nitrate was in the soil. This suggested that the reaction of the woodland soil (pH 6.8 as reported, 13, p. 228) and the ground limestone added in the sand experiment (13, p. 220) were contributing factors to the frenching in the early work. Attention was called to this at the time (8). Brief references to the later studies have been made in annual reports of the Experiment Station (forty-third, 1930, p. 23; forty-fourth, 1931, p. 21). From these studies frenching seems to be induced, so far as the soil is concerned, by a certain condition of reaction coupled with a deficient or unbalanced nutrient supply, other nutrients than nitrogen entering in. Part of the studies seem to show this quite clearly, even suggesting that the entire effect of the soil on frenching is here. This part will be presented first. The other part makes this uncertain and definite conclusions are impossible.

SOIL REACTION AND FRENCHING

Reference to soil reaction or liming and frenching has been made in several publications (8, 11, 13). Frenching was observed at several of the Kentucky outlying soil experiment fields. It was confined largely if not altogether to limed plots. The record, in some detail, of its appearance on these fields is as follows:

The Hopkinsville field[1] was operated from 1922 to 1929 inclusive. Considerable frenching developt in 1923 and 1928 when Burley was grown and in 1924 when dark tobacco was grown. In each year it was restricted to the limed plots except that considerable developt on a check plot next to a macadam road. Samples of soil from this plot effervesced with acid and tested neutral or basic in the laboratory, no doubt because of limestone dust blown upon the plot from the road.

The Greenville field[2] has been operated since 1913. Severe frenching was reported in 1915 in Burley tobacco on a plot which

[1] Fertilizer and lime treatments, rotations, and crop yields are given in Bul. 299 of the Kentucky Agricultural Experiment Station.

[2] Fertilizer treatments, rotations and crop yields of this, the Campbellsville and Mayfield fields are given in Bul. 322 of the Kentucky Agricultural Experiment Station.

had been limed.[3] Dark tobacco was grown on the other plots and no frenching developt on unlimed or limed plots. Different cropping may have accounted for the difference in frenching. Mixed sorghum and cowpeas were grown on the Burley plot in the latter part of the previous summer and removed from the plot. The other plots were left undisturbed in second year red clover sod. In 1928 considerable mild to severe frenching developt in dark tobacco in areas in limed plots. None was observed on unlimed plots.

Tobacco has been grown on the Campbellsville field since 1922; dark tobacco up to and including the 1926 crop; Burley thereafter. Frenching was present each year except 1922 and 1930. It is not certain that it was absent in 1922. The weather was very dry and unfavorable for frenching in 1930. No frenching was observed on unlimed plots. In several years much frenching was present, often of a severe type, in areas on the limed plots. On August 23, 1932, it was estimated that 90 percent of the plants (most of them beginning to bloom) on plot 8, treated with limestone and superphosphate, were frenched. On July 17, 1929, 17 percent of the plants (6 to 15 inches high) on this plot were frenched, the disease ranging from mild to the severe or strap-leaf type.

The Russellville field was operated from 1913 to 1924.[4] Dark tobacco was grown except in 1923 when Burley was grown in a small plot on limed land. No frenching was reported in dark tobacco. The Burley tobacco frenched severely.

Frenching has never been reported at the Mayfield field where dark tobacco has been grown, except in one year when a few plants frenched on a limed plot.

Soil from limed and unlimed plots of the soil experiment fields has been used in greenhouse tests[5] as follows:

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[3] In the early records, frenching was not always clearly distinguished from mosaic disease. It is very probable, however, that this was frenching.

[4] Fertilizer and lime treatments, rotations, and crop yields are given in Bul. 272 of the Kentucky Agricultural Experiment Station.

[5] The tests were made mainly to obtain information on the relation between nutrients and frenching. Unless otherwise stated, one-half gallon glazed earthenware jars were used, each containing about 1,600 grams of dry soil. To facilitate aeration and moisture distribution, glass tubes, one to two inches in diameter, were placed in the jars. These extended from a short distance above the soil surface to the bottom of the jars. Distilled water was added as necessary for optimum plant growth. Two Turkish

Russellville; one test, using soil from unlimed and limed plots.

Mayfield; three tests, using soil from limed and unlimed plots in each; two, using soil from limed plots; and one, using soil from an unlimed plot.

Lexington; three tests, using soil from limed and unlimed plots in each; and one, using soil from a limed plot.

Campbellsville; six tests, using soil from limed and unlimed plots in each; three, useing soil from limed plots; and one, using soil from an unlimed plot.

Greenville; two tests, using soil from limed and unlimed plots in each; and one, using soil from a limed plot.

In these tests frenching did not develop in plants in the unlimed soils irrespective of nutrient conditions but invariably developt in plants in the limed soils unless controlled by addition of nutrients as described later.[6]

Frenching was studied on a number of farms and often soil samples were taken from areas where frenching was present.

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tobacco plants were grown in each jar. Turkish tobacco was used instead of Burley because the former plants occupy less space. Some information as to relative susceptibility of Turkish and Burley tobacco to frenching was obtained in 1932. One row of Burley and an adjacent row of Turkish tobacco were grown in a plot in an area on the Experiment Station farm where frenching frequently develops. Frenching was as follows:

	Plants not frenched	Plants frenched		
		Mild	Medium	Severe
Turkish	1	4	13	12
Burley	1	11	9	8

Procedure in the sand tests reported later was very similar to that in the soil, unless otherwise stated. About 2,000 grams of dry sand were contained in each jar.

[6] As a part of an experiment, the remainder of which is reported later (p. 97), Turkish tobacco was grown in four jars which contained soil from a phosphated but unlimed plot of the Campbellsville soil experiment field. Two bottles were placed in each jar and the plants rooted along the stem in solutions in these bottles as described on page 97. The solutions then were removed from the bottles and sand and nutrients added as follows: The bottle for one plant in each jar received sand, 1 gram of precipitated $CaCo_3$, .25 gram $NaNO_3$ and .25 gm. $NaH_2PO_4 \cdot H_2O$. The bottle for the other plant in each jar received sand and the nutrients but no $CaCO_3$. Acid treated and washed white silica sand was used from a former experiment where a small amount of $Ca(NO_3)_2$ had been added. All plants in these jars frenched after becoming nitrogen deficient and after they were 10 inches high. There was no effect of the $CaCO_3$ on frenching, tho it was expected that the plants receiving this treatment would french and the others not. This is the only possible exception to the statement that frenching has never been observed in plants growing in the greenhouse in unlimed soils from the outlying soil experiment fields.

Some samples of this kind were received, also, from county agents and from farmers. The pH of 65 such samples (after becoming air-dry in the laboratory) was determined, usually colorimetrically. It varied from 5.8 to 7.5 and was from 6 to 6.5 with most samples.[7]

Frequently in the field and greenhouse studies, samples were obtained from areas near by or from other jars in the experiment where plants were not frenched. In the samples from the soil experiment fields, and from the jars in greenhouse experiments with these soils, there was, as expected, a considerable difference in pH between the limed soils in which plants frenched and the unlimed soils in which they did not. The former were usually near 6.5, and the latter from 5 to 5.5.

Outside the Bluegrass Region, the pH of unlimed soils, which have been tilled for a considerable time, is usually from 5 to 5.5, and that of limed soils usually above 6. Fourteen samples have been received from areas, other than soil experiment fields, from outside the Bluegrass Region, where frenching was present. The pH of these samples was 6 or above, except that one sample was 5.8 and another 5.9. Most of the fields from which these samples came had been limed. The others had been cleared recently from timber and, no doubt, contained considerable native active calcium.

There is considerable frenching of tobacco (Burley) in the Central Bluegrass Region of Kentucky in years when climatic conditions are favorable and most of the study of frenching on farms was in this region. Soils here, in the main, contain much calcium as the soil calcium phosphate, and their pH is usually near or within the range of that of the soils from the areas where frenching was present. For this reason liming was not as important in determining frenching here as in soils which, when unlimed are more acid. Some of the fields examined had been limed and the frenching apparently induced by the treatment; most

[7] This does not necessarily mean that probability of frenching decreases above pH 6.5. It may be, merely, because the pH of most Kentucky soils, even with moderate liming, is not above 6.5.

In this publication, pH values are reported simply as an indication of soil reaction and not to suggest a direct relation between H-ion concentration and frenching.

had not been limed. In 13 fields, soil samples were taken from areas where frenching was present and from areas near by where it was absent. The average pH of the former was 6.2, and of the latter, 6. In these fields other conditions than reaction largely determined the presence or absence of frenching.[8] The fact that, so far as known, there is more frenching in the Central Bluegrass Region than in the part of the State outside the Bluegrass Region, suggests that the large amount of calcium in the former soils is favorable for the disease.[9]

NUTRIENT SUPPLY AND FRENCHING

The early work, as already stated, showed frenching to develop when available nitrogen was exhausted in the woodland soil and in river sand containing pulverized limestone. The woodland soil was used in two subsequent experiments. In both, plants frenched when nitrogen deficiency developt. This soil provided a high level of available mineral nutrients and a lower level of available nitrogen relative to the crop requirements. Plants grew rapidly until checked by nitrogen deficiency but were from the beginning of light green color due to the small amount of soluble nitrogen in the soil. The addition of nitrogen increased growth and prevented frenching. Addition of phosphorus and potassium had no appreciable effect on growth or frenching.

In each of seven experiments with river sand containing pulverized limestone, carried out since the early experiment, there were jars in which nitrogen deficiency and frenching developt together.

Forty different lots of soil obtained, some from fields where frenching was present and some from limed plots of the outlying soil experiment fields, have been used in 60 tests of the relation

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[8] It may be, however, that in much of the Central Bluegrass Region, soil reaction is a factor in absence of frenching. Nineteen samples of Maury silt loam (the most extensive soil type in the Central Bluegrass Region and the one on which tobacco production is most concentrated) were collected in connection with soil surveys of two counties. Their average pH was 5.6, which is slightly below the range of the samples examined from areas where frenching was present.

[9] The calcium content of the surface acre 2,000,000 pounds of Central Bluegrass soils ranges in general from 5,000 to 30,000 pounds; the corresponding figure for upland soils outside the Bluegrass Region is 2,000 to 8,000 (12).

of nutrients to frenching in the greenhouse. Except with three lots, there were jars in each test where frenching developt in plants at or nearly at the time as nitrogen deficiency and hence appeared to be induced by it.

Deficiency of available nitrogen has also been reported to produce frenching in work elsewhere (5).

In the present studies considerable attention was given to frenching which developt when nitrogen was not deficient for plant growth, and to possible nutrient relationships existing here.

Nitrate nitrogen was determined in 69 samples of soils obtained from areas in fields in tobacco where frenching was present.[10] The pounds of nitrate nitrogen per two million pounds of dry soil, omitting two soils where analysis showed the amount to be very large, ranged from none to 180. The average amount was 30 pounds. In 11 samples the amount was above 50 pounds; in 17 samples, from 25 to 50 lbs.; and in 14 samples, 10 pounds and below. In two samples none was present. In but two of these areas were symptoms of nitrogen deficiency observed in the plants.[11]

In connection with 20 of the areas where frenching had developt in tobacco, samples were also obtained from areas near by where frenching was absent. The average amount of nitrate nitrogen in the former areas was 21 pounds in two million pounds of dry soil, and in the latter 31 pounds. This is an appreciable difference; but in general the amount of nitrate nitrogen found in the soils in the field studies indicates that nitrogen was not deficient for growth of plants in at least many of the soils when frenching developt. More detailed information in connection with field areas where plants were frenched and the nitrate content high, is given in Table 1.

It is not known just what the level of soluble nitrogen should

[10] These samples were usually taken from within a distance of 10 inches of the base of plants. Each sample was a composite of surface soil from 6 or more different locations.

[11] Nitrogen, of course, may have been deficient for plant growth in other areas. Obviously symptoms of the deficiency of any nutrient follow and do not precede development of the deficiency. The nitrate content of the soil of some of the areas also may have changed appreciably from the time when frenching appeared to the time when sampled.

TABLE 1. Nitrate nitrogen in the soil of areas in fields where frenching was present in Burley tobacco and the soil nitrate content high. The pH of the soils is also given.

Field	Date of examination	Average height of plants	Approx. percent of plants frenched	Days previous to examination within which frenching probably developt	Pounds nitrate nitrogen in 2,000,000 lbs. of surface soil	pH of soil
		Inches				
Campbellsville soil field*	7/17/29	10	17	15	38	6.5
Moorman	7/7/30	8	50	7	78	6.0
Wallman	7/27/31	3	60	7	54	6.4
Larkin	7/27/31	12	50	7	62	5.9
Davis	8 /3/31	15	60	21	77	5.9
Baxter	8/21/31	4	30	7	64	7.0
May**	9/24/31	15	75	7	120	5.9

* This sample was taken from plot 8 in the fertilizer tests on tobacco which is treated with limestone and superphosphate. The pH was estimated.

** The tobacco in this field had been topped. Frenching was in the suckers.

be in soil to make sure that nitrogen is not deficient for growth of tobacco. In experiments on the Experiment Station farm (unpublished except for mention in the forty-fifth annual report, p. 38), where different nitrate levels were maintained in plots by the addition of nitrogen, Burley tobacco made good growth when the nitrate level was maintained at 25 pounds per acre plow layer. However, larger growth (but usually with poorer quality of leaf) was made when the level was 50 pounds and still larger when the level was 100 pounds. Also, as will be pointed out later, a higher level of nutrients may be required to control frenching than to bring about satisfactory growth.

Further information on frenching, when the soil nitrate content is high, was obtained from the greenhouse soil experiments. The amount of nitrate was determined in the soil of a number of the jars at or near the time when frenching developt in the plants.[12] Information as to frenching and the amount of nitrate nitrogen present in jars where nitrate was high when frenching developt, is given in Table 2. It may not be significant but should be kept in mind, that because of the relatively small volume of soil in which the plants were growing, lowering of soluble nitrogen level here was much more rapid than under usual field conditions. However, in the experiment with the Greenville soil started June 11, 1929, nitrate nitrogen increased from 69 pounds on July 16, one day after frenching appeared, to 119 pounds on August 3, when it had become very severe. In other greenhouse experiments presented later, frenching con-

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[12] In the soil experiments, 3 or 4 cores, each three-eighths inch in diameter, were removed from a jar and nitrate determined by the phenoldisulfonic acid method.

In sand experiments, solution was removed from the bottom of the jars and nitrate determined by the method just mentioned; or more often, presence or absence of nitrate was determined and some idea of the amount obtained by spot plate tests using the diphenylamine reagent (10). This latter test was used also to determine the amount of nitrate in the plants, adding the reagent to a thin section of a leaf petiole. Care was necessary in interpreting these diphenylamine tests since much blue color developt, particularly in the plants up to almost the entire absence of nitrate in the soil or sand.

For a time, tests were made of the amount of water-soluble phosphorus and potassium in samples of soil and plant materials from the greenhouse experiments. However, the information obtained as to plant-nutrient relationships above what was known from treatments of the soil and appearance and rate of growth of the plants in the jars did not seem to justify the work and it was discontinued.

TABLE 2. Nitrate nitrogen in soils in greenhouse experiments at or near the time when frenching developed in Turkish tobacco.

Soil	Date of starting experiment	Jar No.	Plot, and additions in greenhouse	Date of frenching	Nitrate nitrogen per 2,000,000 lbs. dry soil, at date given
					Lbs.
Experiment Station farm	Dec. 5/28	8		Dec. 26	Dec. 28, 43
		11		Dec. 26	Dec. 28, 43
Farm, Fayette Co.	Oct. 28/29	10		Nov. 16	Dec. 6, 35
		12		Nov. 16	Dec. 11, 36
Greenville soil expt. field	June 11/29	110*	Limed plot	July 15	July 16, 69; Aug. 3, 119
Campbellsville soil expt. field	Sept. 17/29	3	Limed plot	Nov. 16	Nov. 22, 116
		7	Limed-phosphated plot	Nov. 16	Nov. 22, 47
Ditto	Nov. 26/29	8	Limed-phosphated plot	Jan. 2	Jan. 2, 200
Ditto	Feb. 10/30	1	Limed plot	Mar. 27	Mar. 24, 168
		5	Limed plot	Mar. 24	Mar. 24, 151
		11	Limed plot	Mar. 24	Mar. 24, 108
Greenville soil expt. field	May 13/30	2	Limed plot	July 31	July 31, 42
Farm, Meade Co.	July 18/30	1		Aug. 4	Aug. 4, 202; Sept. 2, 7
		3	$Ca(NO_3)_2$	Aug. 4	Aug. 4, 242; Sept. 2, 100
		6	$CaH_4(PO_4)_2$	Aug. 8	Aug. 4, 120
		9	$Ca(NO_3)_2$, $CaH_4(PO_4)_2$	Aug. 8	Aug. 9, 300; Sept. 3, 0
Campbellsville soil expt. field**	July 30/30	3	Limed plot	Aug. 20	Aug. 20, 200
Farm, Meade Co.	Oct. 3/30	1		Nov. 12	Nov. 12, 60
		2		Nov. 9	Nov. 9, 80
Mayfield soil expt. field, limed plot	Apr. 15/33	4	$Ca(NO_3)_2$	June 7	June 7, 375
		5	$NaNO_3$	June 7	June 7, 282

* Only one plant was grown in this jar.
** Obtained later than that above.

tinued with no recovery when large additions of $Ca(NO_3)_2$ were being made.

The fact that nitrogen deficiency is associated with frenching (when soil reaction is favorable) and that there is thus a nutrient-frenching relationship, suggests that the frenching developing when nitrogen is not deficient is associated with deficiencies of other nutrients. This also was suggested by an early observation of partial control of frenching at the Campbellsville soil experiment field by the potassium treatment.

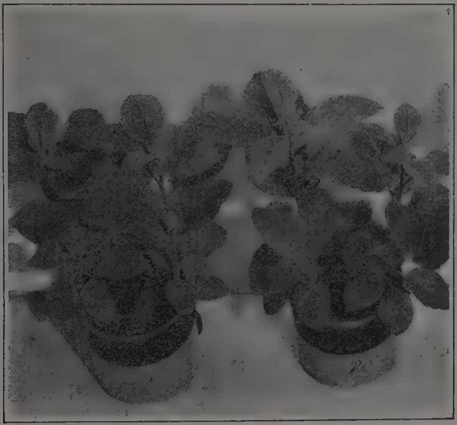

Fig. 1. Turkish tobacco in soil from a limed plot at the Mayfield soil experiment field (see table 8). The plants grew slowly because of deficiency of phosphorus. They frenched when about 4 inches high, when considerable nitrate was in the soil. One and four-tenths grams of $Ca(NO_3)_2.4H_2O$ was applied to Jar 2, three different times, 30, 16 and 9 days previous to taking the picture on June 28, 1933.

Many of the soils used in the frenching studies in the greenhouse were from outside the Bluegrass Region, mainly from the outlying soil experiment fields. Phosphorus is the chief mineral nutrient deficient in these soils. Tobacco makes very poor growth in the field or in the greenhouse on these soils without addition of phosphorus. On this account, limed plots without phosphate treatments were not included in the fertilizer tests on tobacco at the soil experiment fields. A comparison, there-

fore, cannot be made between the amount of frenching on limed and limed-phosphated plots. The considerable amount of frenching observed at these fields on the limed-phosphated plots has already been mentioned. Either phosphorus supply has but little relation to frenching or the applications did not remove phosporus as the deficient nutrient so far as frenching is concerned.

In the general crop rotation tests at these fields there are plots which receive limestone alone and others which receive limestone and phosphate. Turkish tobacco was grown in soil from these plots in a number of experiments (or tests) in the greenhouse. Phosphorus was added in some of these experiments. The soils used, treatments given and frenching observed are shown in Table 3. Plants in the Campbellsville and Greenville soils, without additional phosphorus, frenched with considerable nitrate in the soil. Marked symptoms of deficiency of phosphorus (7) were present when frenching appeared, but none of nitrogen. This was true both of plants in soil from plots which has received phosphate in the field and of those from plots which had not. Plants in the Mayfield limed soil and probably also in the limed-phosphated soil were phosphorus deficient when frenching developt. These plants were also at least near nitrogen deficiency as shown by the absence of nitrate in the soil on February 13.

The phosphorus added to these soils, either in the field or in the greenhouse, did not delay the appearance of frenching. Plant growth, however, was very materially increased and plants in the phosphated soils were larger when frenching appeared than those in unphosphated soils. Also, if enough phosphorus was added, nitrogen rather than phosphorus was the nutrient deficient at the time of frenching.

Potassium is less deficient for tobacco on the outlying soil fields than is phosphorus, but potassium treatments have given some increases in yield of tobacco at all these fields. The early observation on partial control of frenching at the Campbellsville field by the potassium treatment has been mentioned. In 1929 considerable frenching developt in tobacco on the lime-

TABLE 3. Effect of phosphorus on frenching of Turkish tobacco in the greenhouse, using soils from outlying soil experiment fields.

Field	Date of starting greenhouse experiment	No. of jars	Plot treatment	Greenhouse addition	Date of frenching	Average height of plants at date given	Nitrate nitrogen per 2,000,000 lbs. dry soil at date given
				Gms. per jar		Ins.	Lbs.
Campbellsville*	Apr. 16/29	4	Limestone	—	June 12	June 12, 9.5	June 7, one jar 88, another 93
		4	Limestone and superphosphate	—	June 3, 7, 7, and 17 respectively	June 12, 12.5	June 7, one jar 114, another 107
Campbellsville	Sept. 17/29	2	Limestone	—	Nov. 16	Nov. 16, 7	Nov. 22, one jar 116
		12	Limestone and superphosphate	—	Plants in 9 jars on Nov. 16, all others by Dec. 10	Nov. 16, 9.5	Nov. 22, one jar 47
Mayfield	Nov. 26/29	2	Limestone	—	One plant Jan. 26, other Feb. 1	Jan. 29, 5.5	Feb. 13, one jar, none
		2	Limestone and superphosphate	—	Jan. 29	Jan. 29, 10.5	Feb. 13, one jar, none
Greenville*	June 11/29	4	Limestone	—	July 15, 2 July 23, 1 July 26, 1	July 23, 3	July 16, one jar, 69
		4	Limestone	.5 $CaH_4(PO_4)_2$	July 15, 2 July 18, 2	July 23, 22	July 16, one jar, 1.4
Campbellsville	May 28/30	1	Limestone	—	July 7 and 11	July 5, 3.5	July 2, 57
		1	Limestone	.25 NaH_2PO_4	June 30 and July 3	July 5, 14	
		1	Limestone	.5 NaH_2PO_4	June 26	July 5, 16	
		1	Limestone	1 NaH_2PO_4	June 24 and June 30	July 5, 16	July 2, none
		1	Limestone	2 NaH_2PO_4	July 5	July 5, 14.5	

* Only one plant per jar in this experiment.

phosphated plot at this field. On July 17, 20 percent of the plants on this plot were frenched. Frenching was not observed during the year in tobacco on the plot receiving lime, phosphate and 100 pounds potassium sulfate per acre before tobacco. In other years, the potassium treatment had no observed effect on frenching. This treatment also had no observed effect on frenching at the Hopkinsville field. At the Greenville field in 1928, frenching was reduced appreciably by the nitrogen and potas-

Fig. 2. Severe frenching in white Burley tobacco in soil of a type in which potassium sometimes is deficient for this crop and frenching often develops. These plants show potasium deficiency.

sium treatments. Nitrogen appeared to be more effective, however, than potassium.

Potassium is deficient for tobacco in some bluegrass soils. The unusually large amount of phosphorus in many bluegrass soils tends to make potassium more often a deficient nutrient for crops on these than on average soils. There are small areas in the Central Bluegrass Region which as compared with average soils in this region, occupy somewhat lower elevations, are of

darker color, contain more organic matter and have more compact under layers. Symptoms of potassium deficiency were frequently observed in tobacco on these soils in the field studies. Frenching was also frequently observed on these soils.

There is an area of such soil on the Lexington Experiment Station farm. In 1929 Burley tobacco was grown in small plots in this area in an experiment carried on primarily for another purpose. Altho probably unnecessary, superphosphate was applied broadcast at the rate of 600 pounds per acre on the plowed ground and worked into the surface soil. The plots were four rows wide with a border row between. Just before setting the tobacco, nitrogen and potassium fertilizers were applied in the rows of the plots but not in the border rows. Tobacco was set on June 5th. Weather had been somewhat dry before this time but a rain of about 2 inches fell on June 8. Many plants frenched as soon as they began to grow. The fertilizer additions in the row and the frenching in the plants are shown in Table 4. The nitrogen additions reduced frenching only slightly. The nitrogen and potassium additions reduced frenching considerably. Tobacco in the plots receiving nitrogen and potassium also made appreciably better growth than on the plots receiving only nitrogen.

In 1928 Burley tobacco was grown in another part of this area. Many plants frenched severely in the last of July. Trials of $NaNO_3$ alone were made on frenched plants. Pairs of plants (21 in all) were selected to have two plants near each other which were equally frenched. Sodium nitrate in solution was placed around the base of one plant of each pair. Five different rates of addition were made, viz., 78, 156, 312, 624 and 1248 pounds of $NaNO_3$ per acre (calculated on the basis of 7,000 plants per acre). There was general recovery from frenching after the date when the additions were made. However, on the average, the treated plants recovered to a somewhat greater extent than the untreated plants. Later, suckers frenched on all these plants. Eleven of the treated plants of the 21 pairs were as severely frenched as the untreated ones. The other untreated plants were less severely frenched than the treated

TABLE 4. Effect of nitrogen and potassium on frenching of Burley tobacco growing in an area in the Lexington Experiment Station farm where the soil is not typical of the Central Bluegrass Region and tobacco frenches readily.

Row No.	Additions in the row	Number of plants in the row				Total plants in the row	Total plants frenched
		Not frenched	Frenched				
			Mild	Medium	Severe		
	Lbs. per acre						
10	100 $NaNo_3$ and 100 KCl	24	1	0	0	25	1
11	None	11	12	3	1	27	16
12	100 $NaNO_3$	19	11	1	1	32	13
30	116 KNO_3	8	10	5	3	26	18
31	None	2	6	11	7	26	24
32	100 $NaNO_3$	4	10	11	3	28	24
51	100 $NaNO_3$ and 200 KCl	21	6	0	0	27	6
52	None	10	11	3	5	29	19
53	100 $NaNO_3$	12	12	2	2	28	16
56	100$NaNO_3$	6	7	9	5	27	21
57	None	6	4	12	6	28	22
58	100 $NaNO_3$ and 100 K_2SO_4	22	6	0	2	30	8

ones but the difference was slight except with three pairs. Nitrate nitrogen was determined at this time in the soil near the base of plants of two pairs where the $NaNO_3$ additions were the heaviest. The amount per 2,000,000 pounds of dry soil for the untreated plants was 2.4 and 8.0 pounds respectively and 282 pounds for each of the treated plants.

Soil from a part of this area which, so far as known, had not received additions of lime or fertilizers except superphosphate, was used in four experiments in the greenhouse. Plants frenched in soil which received no further additions in each of these experiments. The pH of soil from these jars was approximately 6.5. Nitrogen and potassium were added in two of these experiments. Each increased growth and lessened frenching. Plants did not french in jars receiving both nitrogen and potassium. In the greenhouse, nitrogen was more important than potassium in increasing growth and in controlling frenching.

Greenhouse tests of the relation of nutrients to frenching were made in connection with small lots of soil collected from 21 areas in fields where frenching was present in the tobacco growing in the areas, and from 8 areas each of which was near one of the preceding but where frenching was absent in tobacco growing in the areas. Twenty-two of these samples were from the Central Bluegrass Region and seven from outside the Bluegrass Region.

The following additions were mixed with 400-gram portions (air-dry) of each of the samples:

1. None
2. .1 gm. NH_4NO_3
3. .35 gm $NaH_2PO_4.H_2O$
4. .21 gm. K_2SO_4
5. .1 gm. NH_4NO_3, .35 gm. $NaH_2PO_4.H_2O$
6. .25 gm. KNO_3
7. .35 gm. K_2HPO_4
8. .1 gm. NH_4NO_3, .35 gm. K_2HPO_4

These were placed in small containers and two Turkish tobacco plants grown in each. It was planned to repeat the nutrient additions, in particular the nitrogen additions, as thought necessary to prevent development of deficiencies of the added nutrients. This was done until the plants reached some size; thereafter more or less difficulty was experienced on account of wilting of the plants probably from excess soluble material.

TABLE 5. Effect of nitrogen, phosphorus and potassium on frenching of Turkish tobacco in river sand, in the greenhouse. Started Sept. 22, 1932. Degree of frenching: 1, mild; 2, medium; 3, severe.* Nutrients added, in grams. Height of plants, in inches.*

Jar No.	Sept. 22	Sept. 27	Oct. 17	Oct. 31	Nov. 9		Nov. 26		
1	.5 $NaNO_3$		.05 Na_3PO_4		2.5 2.5		8 8	Nov. 28** 1 1	
2	.5 $NaNO_3$		.05 Na_3PO_4		2.5 2.5		7 8.5	Nov. 29 1 1	
3	.5 Na_3PO_4	.1 $NaNO_3$			2 2 6.5 8 N & K def.	Nov. 12 .25 $NaNO_3$	3 3 9 11		
4	.5 Na_3PO_4	.1 $NaNO_3$			2 2 6 7.5 N & K def.		3 3 7.5 7.8		
5	.5 K_2SO_4	.1 $NaNO_3$	.05 Na_3PO_4		4 4		2 2 9.5 9.5 N def.		
6	.5 K_2SO_4	.1 $NaNO_3$	.05 Na_3PO_4		3 3		5.3 9.5	Nov. 30 1 1 N def.	
7	.5 $NaNO_3$ .5 Na_3PO_4			.5 $NaNO_3$	6.5 7 K def.	Nov. 15 .25 $NaNO_3$	14.5 14.5	Jan. 17† 1 1 29.5 29.5 N def.	

8	.5 $NaNO_3$ .5 Na_3PO_4			.5 $NaNO_3$	7 6 K def.		14 11.5	Dec. 28† 1 1 24 19 N def.	
9	.5 $NaNO_3$ .5 K_2SO_4		.05 Na_3PO_4		3 4		7.5 9	Dec. 17 1 1 15.5 17 N def.	
10	.5 $NaNO_3$ .5 K_2SO_4		.05 Na_3PO_4		3 3		10 9	Dec. 17 1 1 20.5 17.5 N def.	
11	.5 Na_3PO_4 .5 K_2SO_4	.1 $NaNO_3$			1 1 6.5 9 N def.		3 3 8.5 11.5	Dec. 19 3 3 .5 $Ca(NO_3)_2$	Dec. 24 .5 $Ca(NO_3)_2$ Jan. 3 recovered 16 19.5
12	.5 Na_3PO_4 .5 K_2SO_4	.1 $NaNO_3$			2 2 8 5 N def.	Nov. 12 .25 $NaNO_3$	3 3 9.5 7	Dec. 7 2 2	Dec. 19 3 3 17 12 N def.
13	.5 $NaNO_3$ .5 Na_3PO_4 .5 K_2SO_4			.5 $NaNO_3$	10.5 10	Nov. 15 .25 $NaNO_3$	21 20	Dec. 12 1 $Ca(NO_3)_2$	Feb. 4 48 40
14	.5 $NaNO_3$ .5 Na_3PO_4 .5 K_2SO_4			.5 $NaNO_3$	9 9.5		16 20.5	Dec. 12 2 1 N def.	

* Position of frenching and height expressions respectively of one plant in any jar is always at the left in the table and that of the other at the right.

** From diphenylamine tests it was estimated that .25 gm. of $NaNO_3$ was in jar 1. Solution from jar 2 also gave a heavy nitrate test.

† The plants in jars 7 and 8 made abnormal growth, partly because of potassium deficiency, and probably also because of excess of sodium. Terminal growth of these plants continued but the leaves on the lower half of the stems were dead. These plants wilted on bright days. This type of growth probably delayed frenching.

Symptoms of nitrogen deficiency were present in tobacco in the field in but one of the 22 areas in the Central Bluegrass Region. Nitrate nitrogen in the samples ranged, per 2,000,000 pounds of dry soil, from 7 to 180 pounds with an average of 42 pounds. Symptoms of potassium deficiency were present in tobacco in the field in seven of these areas.

The relative extent to which nitrogen, potassium and phosphorus were respectively deficient in these soils in the greenhouse tests was estimated mainly from heights of plants receiving the various additions. In the bluegrass soils nitrogen was usually most deficient and potassium next. In some soils, potassium alone gave a greater increase in plant growth for a time than nitrogen alone. Phosphorus gave a slight increase in growth in some soils when used in connection with nitrogen and potassium.

Nitrogen and phosphorus were almost equally deficient in soils from outside the Bluegrass Region. Potassium gave further increases in plant growth when used in connection with nitrogen and phosphorus.

Frenching developt in the greenhouse in 18 of the 21 soils from areas where frenching was present in the field. It probably failed to develop in the other three soils on account of the very poor growth of the plants in the greenhouse. Frenching developt in the greenhouse in five of the eight soils where it was absent in the field. In connection with the 23 soils, where frenching developt in the greenhouse tests, frenching appeared first in the jars containing the soil which had received no additions in the case of 16 of the 23 soils. It did not develop in plants in jars containing soil to which nitrogen, phosphorus and potassium had been added, except with three jars in which nitrogen was deficient at the time. It was not possible to determine in any definite way the relationship between frenching and supply of the individual nutrients. Deficiency of nitrogen, however, was more common than of phosphorus and potassium.

River sand containing pulverized limestone was used in several experiments on the effect of nutrients on frenching. Details of procedure and the results of one of these are shown in

Table 5. The sand had been used in previous experiments in which more or less frenching had developt and contained small residual amounts of nutrients from these experiments. Two thousand grams were used per jar. The additions made at the beginning of the experiment were mixed with the sand. Thereafter they were added to the surface of the sand in the jars. At

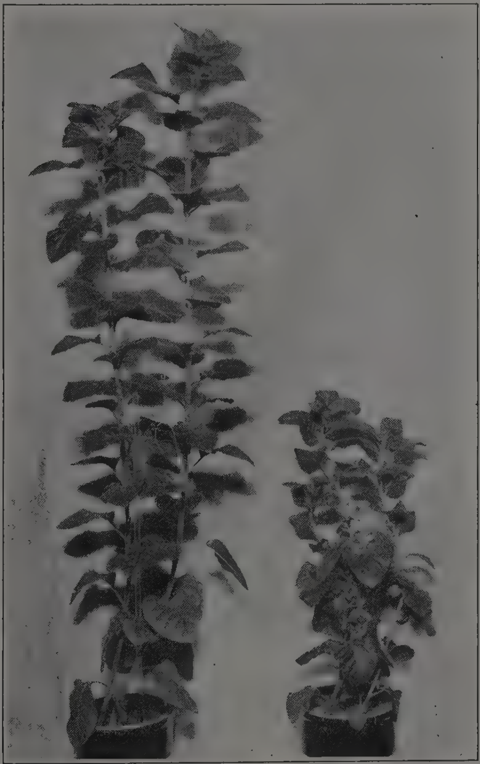

Fig. 3. Turkish tobacco in river sand containing pulverized limestone (see Table 5). The large plants, in jar 13, received liberal additions of nitrogen, phosphorus and potassium and did not french. The medium sized plants, in jar 3, received phosphorus and a small amount of nitrogen (some potassium was in the sand from previous experiments). They frenched when nitrogen became deficient. Symptoms of potassium deficiency, also, had been present for 9 days previous to frenching.

the beginning of the experiment, each jar received .25 gm. $MgSO_4 \cdot 7H_2O$, .001 gm. $MnCl_2 \cdot 4H_2O$ and .0005 gm. H_3BO_3. A solution of ferric tartrate was added as necessary.

The plants in jar 13 that received nitrogen, phosphorus, and potassium in the beginning, and nitrogen thereafter as necessary, made vigorous growth and did not french but those in jar 14, treated the same except that less nitrogen was added, frenched when nitrogen became deficient. Plants in jars 11 and 12 that received phosphorus and potassium, also frenched when nitrogen became deficient. Those in jars 1 and 2 that received nitrogen and a small amount of phosphorus, frenched when there was still considerable nitrogen in the jars. These plants frenched earlier and when considerably smaller than those in jars 9 and 10 that received the same amount of nitrogen and that also received potassium and a small amount of phosphorus. The results indicate that other nutrients than nitrogen affect frenching.

In other experiments with river sand containing pulverized limestone, plants did not french when additions of nutrients were adequate, but did french when nitrogen became deficient, or when nitrogen was not deficient but either phosphorus or potassium or both were. However, these experiments did not show specifically how the different nutrients, in particular the mineral nutrients, were related to frenching.

The work reported so far shows frenching to be related to soil reaction and nutrient supply. Consideration will now be given to parts of the work which limit the extent to which these relationships hold or scarcely seem in line with them.

FURTHER STUDY OF SOIL REACTION AND FRENCHING

As previously reported (8) very little frenching has been observed in a belt of hilly land surrounding the Central Bluegrass Region, the soils of which frequently contain much calcareous material. Most of these soils are high in phosphorus and potassium and usually in nitrogen, so that the nutrient supply perhaps is not often favorable for frenching, but the lack of frenching was unexpected.

In the area of off-type bluegrass soil on the Experiment Station farm already referred to, tobacco has been grown, beginning in 1928, in an experiment in which pulverized limestone was applied in the beginning at eight different rates ranging from 500 to 100,000 pounds per acre. Some frenching developt each year. Considerable frenching, frequently of the severe type, developt in 1928, 1929 and 1932. However, there was very little relationship between quantity of limestone applied and amount and severity of frenching (pH of untreated soil 6.0 to 6.5). In the early experiments (13, p. 228) frenching did not develop in the woodland soil in an experiment in which powdered CaO was added at the rate of 20,000 pounds per 2,000,000 pounds of dry soil. Five successive crops of Turkish tobacco were grown. Four more crops have been grown in the jars of this experiment in the present studies. Frenching developt in the last three crops in the limed soil but never as severely as in the unlimed soil.[13]

In the greenhouse, four crops of Turkish tobacco were grown in small jars of coarse limestone ($^1/_{10}$ to ¼ inch) to which nutrients were added. Deficiency of nitrogen and very probably also of phosphorus and potassium was present at times. Plants usually grew poorly but some became 30 inches high. Frenching did not developt.

In several experiments in the greenhouse, plants were grown in soil with which pulverized limestone was mixed just before potting. Four jars of this kind were started June 11, 1929, with soil from a check plot of the Greenville soil experiment field. Limestone (below 40 mesh) was mixed with the soil at the rate of 20,000 pounds per 2,000,000 pounds of dry soil. Four other jars contained soil from a limed plot, with no greenhouse treatment. One plant was grown in each jar. Plants made very slow growth because of phosphorus deficiency, but frenching had developt in the plants in all the jars of the field-limed soil by July 26. Plants frenched in only two of the other four jars, in one on September 11 and in the other on October 23.

[13] In the last several crops it was necessary to add potassium and phosphorus as well as nitrogen to obtain satisfactory plant growth. In these crops frenching developt in the presence of a considerable amount of nitrate when phosphorus and potassium were deficient.

In October, 1929, in a greenhouse experiment, soil was used which was obtained from an unlimed field in Laurel County, adjoining a limed field in which, at the time, severe frenching had developt in Burley tobacco. Jars were included containing the soil untreated and with ground limestone (below 40 mesh) mixed with the soil at the rate, respectively, of 800, 2,400 and 7,200 pounds per 2,000,000 pounds of dry soil. No frenching developt in plants in the jars that received none or the smallest amount of limestone; some developt in plants in jars that received the medium amount, and more in jars that received the largest amount.

In 1930 in a similar experiment, unlimed and unfertilized soil from the Campbellsville soil experiment field was used (fifteen hundred grams of air-dry soil, in each jar). Different amounts of ground limestone (below 40 mesh) were added with and without phosphate as shown in Table 6. The time that frenching appeared, its subsequent development and the height of plants also are shown. Frenching developt in plants in jars that received one gram and above of limestone, and for a time it was present in jar 12 that received .5 gm. of limestone and phosphate. In the main frenching did not appear earlier or become more severe in plants in jars that received the heavier additions.

In 1932, soil from an unlimed and unfertilized plot of the Mayfield soil experiment field was used in a similar experiment. Limestone (below 40 mesh) was mixed with the soil at ten different rates, ranging from 312 to 50,000 pounds per 2,000,000 pounds of dry soil. One gram of $CaH_4(PO_4)_2$ was added to each jar. There were duplicate jars for each treatment. Plants made poor to only fairly satisfactory growth, but averaged 18 inches in height 50 days after being set. No frenching had developt at this time and the plants were removed. The soil in each jar was emptied into a pan, the larger roots removed, .5 gm. $CaH_4(PO_4)_2.H_2O$ mixed with it, and then it was returned to the jar. A second crop was grown. Frenching did not develop in plants in jars to which 2 grams or less of limestone had been added. Frenching developt in plants in 7 of the 12 jars to which

TABLE 6. Effect of different amounts of limestone on frenching of Turkish tobacco in soil from a check plot of the Campbellsville soil experiment field.

No. Jar*	Limestone added	Frenching and date of appearance	Subsequent frenching	Average height of plants Dec. 23
	gms.			Inches
1	0	None		13
2	0	None		13.8
3	.25	None		10.5
4	.5	None		14.5
5	1	One plant Jan. 12, other Jan. 20	Medium	10.8
6	2	Jan. 4	Severe	10
7	4	Jan. 6	Severe	9
8	8	Feb. 9	Severe	7
9	0	None		38
10	0	None		40
11	.25	None		36
12	.5	December 13	Recovered by December 23	37.5
13	1	November 29	Severe	36
14	2	One plant Nov. 28, other Dec. 5	Severe	32
15	4	One plant Nov. 16, other Nov. 22	Severe	33.5
16	8	One plant Nov. 18, other Nov. 20	Severe	36

* Each of jars 9-16 inclusive, received 1 gram of $CaH_4(PO_4)_2 \cdot H_2O$ at the beginning of the experiment.

4 grams of limestone, or more, had been added, but it was more severe in plants in jars with the lower than with the higher additions.

In the studies reported in this publication, frenching did not develop with soils which were below a certain reaction or calcium content. But it did not usually increase in frequency or severity with increasing lime additions beyond a certain point,

Fig. 4. Turkish tobacco in acid-treated and washed white silica sand (see p. 89). The pH of the solution in each jar was kept within 6.2-6.5. From right to left, the plants in the first jar received sufficient of all nutrients for vigorous growth. Those in the second were deficient in nitrogen; in the third, in phosphorus; and in the fourth, in potassium. No frenching developt, tho the H-ion concentration and nutrient deficiencies associated with frenching in soil were present. This indicates that H-ion concentration, *per se*, does not affect frenching.

in fact the contrary seems to have been true in some experiments.

It is not certain how soil reaction affects frenching. It appears that frenching is not directly an effect of H-ion concentration. Early in the present studies, Turkish tobacco was grown in water and sand cultures in which pH was kept within the

range of that of the soils where frenching was observed and deficiencies of nitrogen, phosphorus, and potassium, singly and in combinations, were brought about. No frenching developt. Acid treated and washed white silica sand was used in the sand experiments. In one of these, the pH of the nutrient solution in most of the jars was kept within 6.2 to 6.5 during the experiment. The pH of the solution containing only the nutrient salts was below this, and lime water was added to bring it up. Deficiencies of nitrogen, phosphorus, and potassium were brought about. The pH value and concentrations desired were maintained by frequent change of solution in the jars. The plants made large growth in the full nutrient cultures. They developt typical deficiency symptoms in the different deficiency cultures, but at no time did symptoms of frenching develop.

It is more probable that the effect of soil reaction is one of calcium supply. Presumably calcium could affect frenching in any of the several ways in which this constituent is known to affect soils and plant growth. However, there is some evidence that the effect is at least largely within the plant. Calcium in the carbonate or basic form, may affect plant growth by reducing availability of phosphorus and potassium; but it is believed that this effect was prevented in many experiments where frenching developed when nitrogen became deficient, by liberal additions of phosphorus and potassium. Attention has already been called to the frenching with river sand containing pulverized limestone. Perhaps the number of ways in which $CaCO_3$ can affect plant growth are fewer here than in soil and the probability is increased, that the effect on frenching is within the plant.

In several greenhouse experiments it was noticed that $Ca(NO_3)_2$ was not so effective in bringing about recovery from frenching as $NaNO_3$. This suggests that calcium is the factor in the effect of reaction on frenching. The effect of calcium nitrate on recovery from frenching was compared with that of sodium nitrate in two experiments. In one, river sand was used which had been used in former experiments. It was leached to remove most of the soluble material remaining from the previous experiments. The plan of the experiment and the

TABLE 7. Effect of $NaNO_3$ and $Ca(NO_3)_2$ on frenching of Turkish tobacco in river sand in the greenhouse. Started April 8, 1933. Degree of frenching: 1, mild; 2, medium; 3, severe.* Nitrate added, in grams. Height of plants, in inches.*

Jar No.	April 8	May 11	May 13	May 19	May 24	May 30	June 12
1	.5 $NaNO_3$	1 4.3 4	1 1 1 $NaNO_3$	2 1 7 6.5	2 1 9.5 8.3	2 2 13.3 12.3 1 $NaNO_3$	18 15
2	.5 $NaNO_3$	1 1 3.5 4	1 1 1 $NaNO_3$ 1 K_2PO_4	2 2 7.3 7	10.5 10	15 15 1 $NaNO_3$	19 20.8
3	.5 $NaNO_3$	3.5 3.8	1 1 1 $NaNO_3$	1 6.5 6.8	1 1 8.8 9.5	2 2 11.5 12.3 1 $NaNO_3$	1 1 16.3 17.3
4	.5 $Ca(NO_3)_2$	1 1 3.3 4	2 1 1 $Ca(NO_3)_2$	2 2 6 7.8	3 3 8.8 10.8	3 3 12 15 1 $Ca(NO_3)_2$	3 3 15.3 20.8
5	.5 $Ca(NO_3)_2$	1 1 3.3 3.3	2 1 1 $Ca(NO_3)_2$ 1 K_2HPO_4	2 2 7 7	2 2 11.3 11.3	2 2 16.5 16 1 $Ca(NO_3)_2$	3 3 24.8 23.8
6	.5 $Ca(NO_3)_2$	1 1 3.5 3.5	1 1 1 $Ca(NO_3)_2$	2 2 6.8 7	3 3 9.8 10.3	3 3 14 15 1 $Ca(NO_3)_2$	3 3 20 22

* Position of frenching and height expressions, respectively, of one plant in any jar is always at the left in the table and that of the other at the right.

effect of the additions on growth and frenching are shown in Table 7. Twenty-one hundred grams of sand were used per jar. The additions at the beginning of the experiment were mixed with the sand. Thereafter they were added to the surface of the sand. At the beginning of the experiment, each jar received .1 gm. $Na_3PO_4.H_2O$, .1 gm. K_2SO_4, .1 gm. $MgSO_4.7H_2O$, .1 gm. $MgCl_2.6H_2O$ and small amounts of $MnCl_2.4H_2O$ and H_3BO_3. A solution of ferric tartrate was added as necessary.

Frenching developt slightly sooner in the plants in jars that received $Ca(NO_3)_2$ than in those that received $NaNO_3$. In general, after the additions on May 13, a mild or medium frenching continued in plants in jars that received only $NaNO_3$, but it became severe in those that received only $Ca(NO_3)_2$. Plants that received $NaNO_3$ and K_2HPO_4 recovered from frenching and did not french thereafter but those that received $Ca(NO_3)_2$ and K_2HPO_4 continued frenched to a medium extent until shortly before June 12 when they became severely frenched.

A comparison of the effect of sodium and calcium nitrate on frenching was also included in an experiment with soil from a limed plot of the Mayfield soil field. The plan of the experiment and the effect of the additions on plant growth and frenching are shown in Table 8. Fifteen hundred grams of air-dry soil were used per jar. Additions at the beginning of the experiment were mixed with the soil. Thereafter they were added to the surface of the soil in the jars. There was the usual effect of the nutrients on frenching. Plants did not french in jar 11 receiving nitrogen, phosphorus, and potassium, and in jar 12 only when nitrogen became deficient. These plants grew rapidly and to a large size. Plants in jars 9 and 10 that received phosphorus and potassium grew rapidly till nitrogen became deficient when they frenched. Plants in jars that received no additions, or nitrogen only, frenched when small and when much nitrate was in the soil. However, plants in jars 3, 4, 5, and 6 that received nitrogen, frenched later than those in the check jars, 1 and 2; and the plants in jars 4 and 6 which also received nitrogen on June 19, recovered after this date. This, however, may have been due to the slow growth made by these plants.

The difference in effect of sodium nitrate and calcium nitrate, in bringing about recovery from frenching, is shown by the plants in jars 9 and 10, each of which received K_2HPO_4 at the beginning. Plants in jar 9 that received sodium nitrate on May 30, June 12 and June 19 recovered. Those in jar 10 that

Fig. 5. Turkish tobacco grown in river sand containing pulverized limestone (see Table 6). Phosphorus and potassium were deficient. The plant at the left (jar 3) received nitrogen in $NaNO_3$. It frenched to a mild degree. The plant at the right (jar 4) received nitrogen in $Ca(NO_3)_2$. It frenched severely. Calcium is believed to have an effect within the plant conducive to frenching.

received calcium nitrate on the same dates (equivalent nitrogen) did not recover. The small effect of calcium nitrate on recovery from frenching is also shown by the continued severe frenching of the plants in jar 2 after the addition of $Ca(NO_3)_2$. It should be stated, however, that in some experiments $Ca(NO_3)_2$ seems to have been as effective in bringing about recovery from frenching as other forms of nitrogen.

TABLE 8. The effect of nutrient salts, in particular of $NaNO_3$ and $Ca(NO_3)_2.4H_2O$, on frenching of Turkish tobacco in soil from a limed plot of the Mayfield soil experiment field. Started April 15, 1933. Degree of frenching: 1, mild; 2, medium; 3, severe. Nutrients added, in grams. Height of plants, in inches.**

Jar No.	April 15	May 19, 20, 21		May 24		May 30		June 5 and 7 New frenching	
1		1 75 NO_3-N*	1	1 4	1 4.5	2 6	2 5.8		
2		1	1	1 4.5	1 5	3 6.3 1.4 $Ca(NO_3)_2$	3 7.5		
3	1.5 $Ca(NO_3)_2$			4.5 561 NO_3-N*	3.8	7	1 5.5		
4	1.5 $Ca(NO_3)_2$			1.8	2.0	2.5	4	1 375 NO_3-N*	
5	1 $NaNO_3$			4	3.5	5.5	5.5	1 282 NO_3-N*	1
6	1 $NaNO_3$			1† 4 240 NO_3-N* †	4	2 6 1 $NaNO_3$	1 5.8		
7	1 K_2SO_4	13 NO_3-N*		5	1 5	8	1 7.5	1	
8	1 K_2SO_4			1 6	5	8.5	8		1
9	1 K_2HPO_4	1 NO NO_3-N*	1	3 11.5	3 10.5	3 12.8 1 $NaNO_3$	3 11.3		
10	1 K_2HPO_4	1	1	3 11.5	3 13	3 13 1.4 $Ca(NO_3)_2$	3 14		
11	1 $NaNO_3$ 1 K_2HPO_4	1 $NaNO_3$		14	18	19 1 $NaNO_3$	25		
12	1 $NaNO_3$ 1 K_2HPO_4	1 $NaNO_3$		14.5	17.5	21	25		

** Position of frenching and height expressions, respectively, of one plant in any jar is always at the left in the table and that of the other at the right.

*Pounds nitrate nitrogen per 2,000,000 pounds of dry soil.

† May 26.

TABLE 8. The effect of nutrient salts, in particular of $NaNO_3$ and $Ca(NO_3)_2 \cdot 4H_2O$, on frenching of Turkish tobacco in soil from a limed plot of the Mayfield soil experiment field. Started April 15, 1933. Degree of frenching: 1, mild; 2, medium; 3, severe. Nutrients added, in grams. Height of plants, in inches.**

Jar No.	June 12		June 19		June 26		July 10		July 30	
	3	3	3	3	3	3	3	3	3	3
1	11	10	12	11	12	12	12	12		
			NO NO_3-N*							
	3	3	3	3	3	3	3	3	3	2
2	10	12	10.5	12.5	11.5	13	15	16.5		
	1.4 $Ca(NO_3)_2$		1.4 $Ca(NO_3)_2$							
	1	1	1	1	3	3	3	3	3	3
3	12.5	9.5	15.8	12.5	19.8	16	26.3	19.5	35	27
	2	1	2	1	3	2				
4	5	7.3	5.8	9.5	7.5	11.3	11	16.3	17	24.5
	1.4 $Ca(NO_3)_2$		1.4 $Ca(NO_3)_2$							
	3	3	2	2	3	3	3	3	2	2
5	10.5	10	13.8	13.5	17.5	16.5	25.5	23	35	31.5
	3	3								
6	10	10.5	12.3	13	14.8	15.3	21	21.5	28.5	29
	1 $NaNO_3$		1 $NaNO_3$							
	3	3	3	3	3	3	1	1	1	
7	12.5	12.3	14	14.5	16.8	17.5	23.5	23	31.5	31.5
	1.4 $Ca(NO_3)_2$		1.4 $Ca(NO_3)_2$							
	3	3	3	3	3	3	3	3		
8	12.5	12	12.75	12	14.5	14	19	18.5	23.5	22
			NO NO_3-N*							
	3	3	1	1						
9	16.5	16	20.8	19.8	26.3	24.5	37	32.5	Discontinued	
	1 $NaNO_3$		1 $NaNO_3$							
	3	3	3	3	3	3	3	3	1	1
10	15	16.8	17	18.5	18.8	20.3	25.5	27	33	36
	1.4 $Ca(NO_3)_2$		1.4 $Ca(NO_3)_2$							
11	27	33	32.5	37	37.5	41.5	Discontinued			
	1	1	1	1						
12	29	34.5	32.5	38.3	36	42	Discontinued			

FURTHER STUDY OF NUTRIENT SUPPLY AND FRENCHING

Numerous experiments have shown that when reaction is favorable, plants french when nitrogen becomes deficient, or if nitrogen is not deficient, when deficiencies of phosphorus or potassium or both exist. In the greenhouse work, in all experiments, it was possible to prevent the development of frenching or bring about frenching recovery by liberal additions of nitrogen, phosphorus or potassium or combinations of them. In the greenhouse the relation of nitrogen to frenching was the easiest to demonstrate. The available nitrogen level is more easily controlled than that of phosphorus or potassium, and rapid changes which are favorable for frenching, are more easily brought about of nitrogen than of phosphorus and potassium. In several greenhouse experiments, plants which were markedly deficient in phosphorus or potassium did not french until nitrogen also became deficient. In fewer instances, plants failed to french when nitrogen became deficient. Frenching, however, is related not only to reaction and nutrient supply, but to other factors affecting growth. Plants, deficient in phosphorus and potassium, made very slow growth from the time of setting—a condition unfavorable for development of frenching.

Frequently it was not clear what the nutrient-frenching relationship was in the field. From the nitrate analyses, nitrogen, evidently, was deficient for satisfactory plant growth in less than half of the areas where frenching was studied in the field. Deficiency of phosphorus or potassium, or both, were present certainly in a number of these areas and probably in many. However, in a considerable number of the areas, particularly in the Central Bluegrass Region, seemingly nutrients were not deficient for satisfactory plant growth, since frenching developt in rapidly growing plants and on what would be rated as highly productive soils.

The fact that the nutrient-frenching relationship is usually not as direct and consistent as is the nutrient-growth relationship raises the question whether the effect of the nutrient additions on frenching does not come from effects in the soil other than the supply of the nutrient in the addition.

In the early work (13, p. 226), to obviate this possibility, nitrogen was introduced into the upper part of frenched plants growing in the woodland soil. Plants were bent over and rooted in sand in glasses and nitrogen was added at this point. Recovery was as prompt as when the addition was made to the soil.

Experiments of this nature but with less positive results were carried out in the early part of the present studies. In the first two of these, soil from the limed-phosphated plot of the Campbellsville soil experiment field was used. In the first, plants were bent over and rooted in sand as in the early work. In the second, two 150 cc. beakers were placed in each jar so that the tops projected somewhat above the surface of the soil. The plants were bent across these and rooted in solutions. In both these experiments the plants were of considerable size and most of them severely frenched before the special additions were made. The quantities of nutrient added, also, were small. In general, addition of a single nutrient increased plant growth but little. Combinations of nitrogen and phosphorus or of nitrogen, phosphorus, and potassium increased growth of plants appreciably, but had little effect on recovery from frenching. As a matter of fact, most of the plants in these experiments, wholly or in part, recovered from frenching towards the close of the experiment, irrespective of treatment.

The woodland soil was used in the third of these experiments. Two bottles (wide mouth, capacity 125 cc. each) were placed in the soil of each jar so as to extend a short distance above the soil. Plants were set which had been previously rooted for some distance along the stem. Each plant was bent across the bottle near it and the roots on this part of the plant were placed in the solution in the bottle. Into one bottle in each jar, solutions were put containing nutrients as follows: 3 jars, nitrogen; 2 jars, phosphorus and potassium; and 2 jars, nitrogen, phosphorus, and potassium. The salts used per 1000 cc of solution were 1.5 gms. $Ca(NO_3)_2.4H_2O$; .5 gm. $CaH_4(PO_4)_2.H_2O$; .5 gm. KCl. Where single nutrients were used, .5 gm. $CaCl_2.2H_2O$ and .5 gm. Na_2SO_4 were also added. The solutions in the bottles were changed approximately once a

week. Phosphorus and potassium were without effect on growth or frenching. Nitrogen increased plant growth to a large extent. Comparative height (inches) of duplicate plants in the different jars were respectively: nitrogen treated, 17, 17, 22, 20; not nitrogen treated, 11, 11, 12.5, and 17. Mild frenching developt in the plants not receiving nitrogen, in all jars. Some frenching but much less developt in plants receiving nitrogen. The additions, while largely increasing growth, did not prevent frenching altogether.

In the fourth experiment, soil was used from the limed plot of the Campbellsville soil experiment field. Fifteen hundred grams of air-dry soil were used per jar. Bottles were placed in the soil in each jar, as in the previous experiment. Plants of sufficient height were set so that each, at time of setting, could be bent across the bottle nearby and part of the bent stem would extend into the solution. Plants rooted quickly in the solutions. Details of procedure and the effect of the additions on growth and frenching of plants are shown in Table 9. The untreated plants made very slow growth. The effect of the nutrient solutions on growth can be estimated from the heights of plants on April 16. The increases in growth from the various solutions were as follows: phosphorus, large; nitrogen, none or very small; nitrogen and potassium, none or very small; phosphorus and potassium, somewhat more than from phosphorus alone; nitrogen and phosphorus, considerably more than from phosphorus alone; nitrogen, phosphorus, and potassium, somewhat more than from nitrogen and phosphorus.

The nutrients, however, were without observable effect on frenching, plants frenching rather quickly and soon becoming severely frenched[14] irrespective of the treatments, except that the plant in jar 11, rooted in the NPK solution, did not french. The corresponding plant in jar 12 did french, but on April 18 there was no nitrate in the soil of this jar. Likewise there was no nitrate in the soil of jars 2 and 12 and only a relatively small amount in jar 6. Nitrate was still high

[14] Often in these studies frenching developed most rapidly and became most severe when nitrogen was not deficient for plant growth.

TABLE 9. The effect on frenching of Turkish tobacco in the greenhouse of introducing nutrients into the plants above the soil but near their base by rooting them in solutions in bottles set in the soil. Started Feb. 10, 1930. The two plants in each jar are designated, respectively, a and b. Degree of frenching; 1, mild; 2, medium; and 3, severe. Soil from a limed but unfertilized plot of the Campbellsville soil experiment field was used.

Jar No.	Mar. 20 Nutrient solutions used*	Mar. 24	Mar. 28	Mar. 31	Apr. 7	Apr. 11	Apr. 16‡	Apr. 18 Nitrate nitrogen in 2,000,000 lbs. of dry soil
								Lbs.
1	b PK	168 NO_3-N†	b 1	a 1 b 1	a 1 b 1	a 2 b 1	a 3 b 3 a 3.8 b 8	
2	a P					a 1 b 1	a 3 b 3 a 5.5 b 2.8	None
3	a N			b 1	a 1 b 1	a 2 b 2	a 3 b 3 a 1.8 b 1.8	156
4	a N				a 1 b 1	a 2 b 2	a 3 b 3 a 2.5 b 1.8	
5	a P	a 1 b 1 151 NO_3-N†	a 1 b 1	a 2 b 1	a 3 b 1	a 3 b 2	a 3 b 3 a 4 b 2.5	
6	a PK					a 3 b 2	a 3 b 3 a 4:5 b 2	19
7	a NP					a 1	a 2 b 2 a 8 b 2	
8	a NP			b 1	b 1	b 2	a 3 b 3 a 9 b 3	
9	a NK					a 1 b 1	a 2 b 2 a 2.5 b 1	81
10	a NK		a 1 b 1	a 1 b 1	a 1 b 2	a 2 b 3	a 3 b 3 a 2 b 2.5	
11	a NPK	a 1 b 1 108 NO_3-N†	b 1	b 1	b 1	b 1	b 2 a 11.5 b 3.5	None
12	b NPK				a 1 b 1	a 2 b 1	a 3 b 3 a 1.5 b 9.5	None

* The salts used in grams per 1000 cc of water were: Check solution for all plants not in nutrient solutions, .5 $CaCl_2.2H_2O$. .5Na_2SO_4. Nitrogen solution, 1.5 $NaNo_2$, .5 Ca Cl_2.2 H_2O. Phosphorus solution, .5 $NaH_2PO_4.H_2O$, .5 $CaCl_2.2H_2O$. Nitrogen and potassium solution, 1.5 $NaNO_3$, .5 KCl, .5 $CaCl_2.2H_2O$. Phosphorus and potassium solution, .5 $NaH_2Po_4H_2O$, .5 KCl,.5$CaCl_2.2H_2O$. Nitrogen, phosphorus and potassium solution, 1.5 $NaNO_3$, .5 $NaH_2Po_4.H_2O$, .5 KCl. Fresh solutions were put in each bottle on April 4 and April 10.

† Pounds nitrate-nitrogen per 2,000,000 pounds of dry soil.

‡ Height of plants in inches is also shown in this column.

in jars 3 and 9, because the plants had made but small growth due to phosphorus deficiency and had not removed much nitrate from the soil. The absence in the main of any effect on frenching from the nutrient solutions in this experiment was unexpected. Apparently, uptake of nutrients from the solutions was not rapid enough to control frenching. Were it not for the close relationship between nutrient supply and frenching which has been found in numerous experiments with soil and with river sand, it would appear that the effect of nutrient salts on frenching is indirect and of secondary nature. Certainly the relationship between nutrient supply and frenching was not nearly as close as between nutrient supply and growth.

The possibility that other nutrients than nitrogen, phosphorus, and potassium affect frenching has been considered. Deficiency of iron developt in a number of experiments with river sand where frenching developt. Typical symptoms of iron deficiency appeared but there was no suggestion of any relationship to frenching. Frenched plants also were sprayed with iron solutions with no effect on recovery.

In the greenhouse tests with soil obtained from fields where tobacco was frenched, sulfur deficiency appeared in plants in some of the jars containing soils from the Bluegrass Region (two plants growing in 400 grams of soil, watered with distilled water). Frenching also developt in these plants, but its development and recovery seemed to be independent of sulfur deficiency. In work[15] in the past, field treatments of sulfur did not increase yields of general farm crops and there is no reason to believe that sulfur deficiency is related to the frenching developing in the field.

Symptoms of deficiency of magnesium are rare in tobacco in the field in Kentucky and, while very little experimental work has been done on the point, it is probable that magnesium is deficient for tobacco in very few Kentucky soils, and there is no reason to believe that magnesium deficiency is related to frenching in the field. Symptoms of magnesium deficiency did not appear in plants grown in soils in the greenhouse in the present

[15] Unpublished work by E. M. Johnson of this Experiment Station.

studies even when several crops were grown in the same jars. These symptoms did appear in plants in several jars in the experiments with river sand but there was no observable relationship to frenching.

In reporting the early work (13) the similarity of frenching of tobacco to such diseases of tree crops as pecan and apple rosette, was pointed out. In the present studies a chlorosis, similar to that of frenching, developt in the growing points of petunias and tomatoes in soils in which Turkish tobacco invariably frenched. Frenching in petunias developt in plants growing (1) in the woodland soil, (2) in a sandy loam soil from

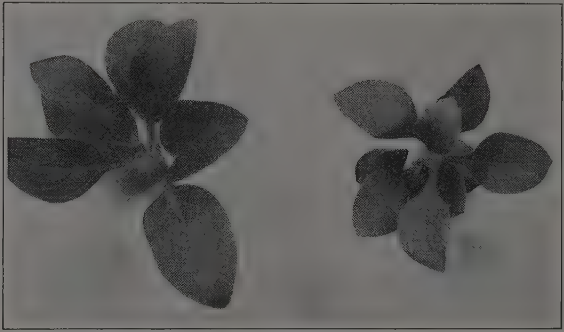

Fig. 6. "Petunias grown in the woodland soil. The one at the right shows the chlorosis which sometimes develops in these plants in this soil. This chlorosis is probably the same as the chlorosis in frenching of tobacco.

outside the Bluegrass Region in which tobacco frenches easily and (3) in soil from the area on the Experiment Station farm where the soil is not the usual type in the Central Bluegrass Region.

Frenching of tomatoes developt in this latter soil. Two crops were grown in the greenhouse in the same jars of this soil. In the first, one Turkish tobacco plant and one tomato plant were grown in each jar. Sixteen jars were in the experiment. Frenching developt in tobacco plants in 14 jars and in tomato plants in 6 jars. Tomatoes frenched considerably later than

tobacco. In the second crop, three tomato plants were grown in each jar. Over two-thirds of these plants frenched.

Six pecan trees on the Experiment Station farm are located near a macadam drive. Rosette has developt in all these trees, ranging from mild in some to severe in others. After the papers appeared (3, 4) on the control of rosette by zinc treatment, affected terminal growths of these trees were dipped in $ZnSO_4$ solutions. Practically entire recovery resulted.[16]

Deficiency of copper has been reported to produce a chlorosis of deciduous fruit trees (1).

These and other treatments were tried in connection with frenching of Turkish tobacco in the greenhouse. In most of this work frenched tops of Turkish tobacco plants were dipped in or sprayed with solutions of salts of the various elements. In one experiment zinc sulfate also was mixed with river sand. None of these treatments[17] had any effect in bringing about recovery from frenching so far as could be observed.

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[16] Treatments the previous season with iron solutions had given no recovery.

[17] Jars were selected in which the two plants were approximately equally frenched. One plant in each jar was treated, the other served as a check. Solutions were applied to frenched parts of plants as follows:

I. Plants in river sand. One plant in a jar was sprayed at three different times with a solution of .1 gm. $ZnCl_2$ in 1000 cc of distilled water. One plant in another jar was sprayed in the same way with a solution of .1 gm. $MnCl_2.4H_2O$ in 1000 cc of distilled water.

II. Plants in limed soil from the Mayfield soil experiment field. One plant in each of five jars was dipped once in a solution of 1.8 gms. $ZnSo_4$ in 1000 cc distilled water.

III. Plants in river sand. Two solutions were made containing .1 gm. of each of the following salts in 1000 cc of distilled water:

(a) $MnSo_4.4H_2O$, $CuSO_4$, $Co(NO_3)_2,6H_2O$, $ZnSO_4$ KI. $Al_2Cl_6.12H_2O$, $NiSO_4.6H_2O$, $Sr(C_2H_3O_2)_2$.

(b) Ti_2Cl_6, $BaCl_2.2H_2O$.

Plants were dipped 4 times in these solutions at intervals of 3 to 4 days as follows:

(1) One plant in each of four jars, in solution (a).
(2) One plant in each of four jars, in solution (b).
(3) One plant in each of four jars, in solution (a) and then on the following day in solution (b).

Also the solutions were sprayed on frenched leaves of other plants in this experiment. Usually three leaves on a plant were treated. The remaining frenched leaves on the plant served as checks. The solutions were applied singly and in combination as in the dipping treatments. Two applications were made.

The solutions, also, were introduced into the midvein of frenched leaves of other plants by using a hypodermic needle. Each leaf received only one solution and injections (usually three per leaf) at only one time.

Reports have come to our attention of the recovery of frenched tobacco cuttings in solutions of manganese salts. Recovery under such conditions means but little since any condition which for a time markedly retards growth, usually brings about recovery from frenching. In one of the experiments with river sand, a cutting 4 inches in length was removed from the top of a plant which was frenched to a medium degree. The lower part of this was placed in the sand in the jar. The cutting grew and entirely recovered from frenching. At the same time suckers growing from the top of the plant from which the cutting had been removed, frenched. The duplicate plant in the jar also continued to be frenched to a medium degree. Frenched tops of plants were placed in solutions of (1) NaCl and (2) $MnCl_2.4H_2O$ containing .1 gm. of the salt in 1,000 cc of solution. It is not certain that any real recovery resulted; certainly any changes in this direction were less in the manganese solution than in the check solution.

It was thought there might be a relationship between amount of sunshine or shading and frenching. In an experiment in the greenhouse, plants in different jars were subjected to different light conditions as follows: (1) the usual greenhouse conditions; (2) usual greenhouse conditions during the day and artificial light during the night; (3) shaded to considerably reduce the light during the day. Plants in all the treatments frenched but there was no significent effect of the treatments on time or severity of frenching.

The most obvious characteristic of frenching is its restriction to the growing points of plants. Frenched plants may continue to grow about as rapidly as if not frenched. New leaves as they appear develop the frenched condition but later recover and, except for the frenched top, the plant appears to be normal.[18] Frequently, when plants were frenched so severely that terminal growth was practically inhibited, leaves below the frenched part continued to grow at the usual rate or even more rapidly on account of absence of terminal growth. This was well shown by the growth of the non-frenched parts of

[18] Growth of frenched plants of this sort is described by Valleau and Johnson (13, p. 193).

plants in certain jars in the greenhouse experiment with soil from the Mayfield soil field (p. 91.) As already stated, plants in jars receiving $Ca(NO_3)_2$ continued to be severely frenched, but plants receiving $NaNO_3$ recovered. However, the parts of the former plants, below the frenched tops, grew more rapidly than the corresponding parts of the other plants.

It may be that frenching is the result of difficult translocation, perhaps, of simple protein materials from the older part into the growing point particularly into the leaf tissue between the veins. This is further suggested by the deep green color frequently found in and along the larger veins of frenched leaves and the chlorotic condition in between, and by the strap shape of leaves on severely frenched plants produced by rapid growth of the midvein and slow growth of the rest. The effect of calcium could be within the plant, on mobility of these protein compounds. This might decrease with increase in amount of calcium up to a certain point, after which, perhaps, the effect might even be reversed.

With respect to the effects of nutrients in frenching, it could be assumed that when translocation is proceeding with difficulty, a liberal supply of nutrients entering into formation of the simple protein compounds would enable the process to continue in such a way as to make normal growth possible. The effect of nutrients on frenching, thus, would be less direct than on growth and a higher level of nutrients would often be required to prevent or give recovery from frenching than to make possible satisfactory growth of normal plants.

If frenching results from impeded translocation, rapidly-growing plants would be more susceptible than slowly growing plants. Field and greenhouse observations suggested that this is true. In the greenhouse work, in some jars, one plant grew more rapidly than the other. In 26 of these jars the taller plant frenched first and in 14 the shorter plant frenched first.[19]

[19] Usually duplicate plants in jars grew about equally fast and frenched on the same day. In one experiment there were 12 jars containing soil from the limed-phosphated plot of the Campbellsville soil experiment field. Both plants in eight of these jars frenched on the same day. The remaining plants frenched within two days before or 6 days after this time, except one plant which frenched 19 days after this time.

The rapid growth of plants after rains, because of abundant moisture supply, very probably accounts for the frequent frenching at this time, altho the common belief among farmers is that it is the result of a wet soil condition, unfavorable for plant growth. In greenhouse experiments, the latter condition, delayed or prevented frenching instead of bringing it about. It is commonly believed, also, that the more frequent frenching on bottom land than on upland is because of the poor drainage and unfavorable condition for growth on such land. Again the probability is that a better moisture supply in such land brings about more rapid growth. In addition, however, these soils are usually less acid, and more often within the reaction-frenching range than nearby uplands.

This relationship of frenching to rate of growth probably explains why frenched plants generally recover in periods of dry weather. In the greenhouse work with soil it was not uncommon for plants that frenched when available nitrogen supply was exhausted to recover without addition of nitrogen because in time growth adjusted itself to the nitrogen becoming available from the soil.

The tendency for frenched plants to recover when growth is retarded also probably explains any effect of the practices sometimes used by farmers of pulling plants until the roots are partially broken loose from the soil, or of cultivating deeply close to the plants. But probably these characteristics of frenching could be made to fit into some other explanation and this should be kept in mind.

The work reported was done almost altogether in connection with soil and river sand. However, reference (p. 88) was made to water and sand culture experiments where distilled water, acid treated and washed sand and analyzed chemicals of c. p. grade were used. This was done before it appeared probable that the effect of reaction on frenching was connected with calcium supply which perhaps was not favorable for frenching.

After this, eleven experiments were made in which acid treated and washed sand and distilled water and c. p. chemicals were used and in which jars were included containing different

Fig. 7. Turkish tobacco in soil from a limed plot at the Mayfield soil experiment field (jar 8 in Table 8). Phosphorous and probably nitrogen were deficient when the plants frenched. Nutrients were not applied but the plants adjusted themselves to the small supply available from the soil, grew slowly and, in time, recovered from frenching.

amounts of lime materials. In three of these, precipitated calcium carbonate was used and in ten, ground limestone, below 40 mesh, containing approximately 98.5 percent $CaCO_3$. Plants did not french where no lime material and where precipitated $CaCO_3$ was used. Plants frenched in four of the ten experiments where ground limestone was used. Nutrients were re-

lated to the frenching which developed as in the soil and river sand experiments.

It is not clear why plants frenched less easily in these sand cultures[20] than in river sand or soil. Possibly it was because of a difference in calcium and nutrient supply in relation to plant growth or perhaps calcium and nutrient supply relate themselves to frenching only in connection with some other factor which is less active in the acid treated and washed sand than in river sand and soil. If it should be found that some rare element is related to frenching of tobacco, as is zinc to rosette of pecans, the effects of nutrients and calcium or of reaction on frenching, described in this publication, doubtless, could be thru or in connection with this. If this is true, however, it would seem that frenching should be more easily obtained in the acid-treated and washed-sand cultures than in river sand and soil.

It has been suggested that frenching may be due to a toxic agent (9). Again the calcium and nutrient conditions found associated with frenching could function in connection with this. On the basis of present knowledge, however, it seems less likely that frenching is caused by a toxic agent than by deficiency of a rare element. In particular, while possible, it would seem unlikely that the frenching in the greenhouse experiments with the acid-treated and washed sand, c. p. chemicals, and very high grade limestone was of toxic origin.

SUMMARY

Studies of frenching of tobacco are reported consisting mainly of: (1) Observation of frenching in plants in the field and in the greenhouse in soil and sand cultures where the lime and fertilizer treatments were known; (2) determination of nitrate and pH of soils where frenching developt; (3) production and control of frenching in plants growing in sand and soil (mainly in the greenhouse), with addition of lime materials and nutrients; (4) applying to frenched parts of plants, solutions

[20] It was observed in these cultures that frenching was less likely to develop and, where present, was somewhat less severe in the first crop, then in succeeding crops in the same jars. This was also true of frenching in plants in river sand.

containing various elements including those found to give recovery from other chlorotic diseases.

Frenching was found to be related to soil reaction and supply of nutrients as follows: It did not develop with soils of moderate or strong acidity, irrespective of the supply of nutrients. With soils less acid than these, it developt when the amount of nitrogen, phosphorus or potassium, singly or in combinations, available for plant use, was low, and did not develop when a high level of these nutrients in available form existed during plant growth. Sufficient additions of these nutrients, also, brought about recovery of frenched plants.

Samples of soils with which frenching developt, ranged in pH from 5.8 up. A large number of those examined were from 6.0 to 6.5. It appeared that the effect of reaction on frenching was one of calcium supply and that the effect of calcium was mainly within the plant. While frenching was not observed in acid soils, it was not, usually, more common or severe in soils which had been heavily limed than in those only slightly acid; in fact there is some evidence that there was less frenching in the former than in those neutral or slightly acid.

The relation of frenching to the supply of nutrients was not so direct and consistent as the relation of growth to this supply. Often it was necessary to add a larger amount of nutrients to control frenching than to give satisfactory growth of unfrenched plants. The relation between phosphorus and potassium deficiency, and frenching was not so specifically or perhaps clearly shown in the greenhouse as that of nitrogen. However, frenching frequently developt in the greenhouse with much nitrate in the soil or sand, and when phosphorus or potassim or both were deficient. It was also necessary to maintain a high level of the three nutrients in available form during growth of the plants to prevent development of frenching when reaction was favorable. In studies in the field, the relation of frenching to the supply of nutrients was not always clear. In some areas where frenching occurred, nitrogen was deficient; in others, phosphorus or potassium or both. However, in a considerable number, seemingly, nutrients were not deficient for satisfactory crop

growth, and an effect of nutrient deficiency on frenching would have to depend on a higher level of nutrients being required to prevent frenching than to give satisfactory plant growth.

It was pointed out that frenching, primarily, is a disease of the growing points of plants which suggested that it is the result of slow translocation, perhaps, of simple protein compounds into the growing point. Calcium could function in this connection in affecting mobility of the protein compounds and nutrient supply, in that a high level would enable normal growth to proceed when translocation was slow.

Frenching in plants in soil and river sand in the greenhouse was rather easily brought about by proper addition of pulverized limestone and adjustment of nutrient supply. It was more difficult to obtain frenching when acid-treated and washed white silicia sand was used.

Magnesium, sulfur, iron, manganese, copper, zinc, and a number of other elements were not found related to frenching, in the work done.

Work was not done on the possibility that frenching is of toxic origin because this was not thought probable in view of the conditions known to be associated with frenching.

While the results of the studies rather clearly show frenching to be related to soil reaction and nutrient supply as described, yet for various reasons it can not be concluded that other causal factors are not present with which or thru which the reaction and nutrient factors may function. And it may be, even, that reaction and nutrient factors merely suppress or bring into activity some other factor which is the underlying cause, somewhat as moisture supply affects frenching by affecting rate of growth.

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